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TECHNICAL REPORT NO. 66-93

MULTICOMPONENT STRAIN SEISMOGRAPH

Quarterly Report No. 5, Project VT/5081

1 July to 30 Sept. 1966

TELEDYNE INDUSTRIES
GEOTECH DIVISION
GARLAND TEXAS

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TELEDYNE INDUSTRIES
GEOTECH DIVISION
3401 Shiloh Road
Garland, Texas

19 October 1966

IDENTIFICATION

AFTAC Project No.	VELA T/5081
Project Title:	Multicomponent Strain Seismograph
ARPA Order No.	624
ARPA Code No.	8100
Contractor:	The Geotechnical Corporation Garland, Texas
Date of Contract:	1 July 1965
Amount of Contract:	$272,651
Contract No.	AF 33(657)-15288
Contract Expiration Date:	31 December 1966
Project Manager:	R. C. Shopland, BR 1-2561

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ABSTRACT

Phase response tests of the magnetostrictive calibrator on the vertical strain seismometer indicate that the calibrator is the chief cause of phase lag measured at the output of the seismometer during calibration. Further tests are necessary to resolve existing phase uncertainties, which are less than about 10 degrees at frequencies below 3 cps, and larger than 10 degrees above 3 cps.

Spectra of microseisms recorded by the vertical strain, crossed horizontal strains, and their summation were examined to determine the similarity of the outputs of the strain seismographs. Only at spectral peaks were the vertical and crossed horizontal strains found to have about equal response.

A preliminary examination of the ability of the north and east summed horizontal strain and inertial seismographs to reject microseisms was undertaken employing spectra. Reduction of about 10 dB was attained for single source microseisms.

The conclusion that true earth strain is being recorded by the vertical strain seismometer is supported by two results: (1) Rayleigh waves at 1 cps are cancelled by at least 15 dB by summing vertical strain and vertical inertial seismograph outputs; (2) the empirical value of the ratio of vertical strain to summed orthogonal horizontal strain is within 12 percent of the theoretical value for Rayleigh waves at 1 cps.

MULTICOMPONENT STRAIN SEISMOGRAPH

1. INTRODUCTION

This report discusses technical findings and accomplishments in a program of strain seismology under Contract AF 33(657)-15288 in the period of 1 July to 30 September 1966. The work reported herein covers development of a system of three-component strain and three-component short-period inertial seismographs having matched amplitude and phase responses in the frequency range 0.01-10 cps.

This report is submitted in compliance with Item 6 of Exhibit A, Statement of Work to be Done, AFTAC Project Authorization No. VELA T/5081. The report is presented in the same sequence as the tasks in the Statement of Work. The Statement of Work is included as an appendix.

2. INSTRUMENTATION DEVELOPMENT

2.1 VERTICAL STRAIN SEISMOMETER WITH VARIABLE CAPACITANCE TRANSDUCER

The second vertical strain seismometer with a variable capacitance (VC) transducer was assembled during this period. This second seismometer is necessary for evaluation of the plastic-cased borehole and for seismometer tests which would normally interrupt data recording.

2.2 PHASE RESPONSE TESTS OF THE MAGNETOSTRICTIVE CALIBRATOR

During the previous quarter, tests of the phase response of the vertical strain seismometer showed an unexplained phase shift averaging 20° in the frequency range between 0.5 and 7 cps. The magnetostrictive (MS) calibrator was suspected as the cause and several phase response tests were conducted.

2.2.1 Laboratory Tests

Laboratory phase tests of the MS calibrator were performed during this period. The calibrator was mounted in the transducer package in place of the moving-coil and magnet assembly. One plate of the VC transducer was

mounted on the calibrator. To avoid temperature variations and building vibration, the test package was sealed and operated in the borehole at Garland.

In the first test, sinusoidal current was held constant and phase responses at several bias currents were obtained. Data indicated an increase in phase lag with increasing bias and with increasing frequency at all bias levels, increases being more rapid at the higher bias levels. A bias current of 4.0 ma was selected for use in all future calibrations of the seismometer and several phase response curves were run at this level to check the repeatability of the test. Results were favorable in the frequency range of 0.1 to 3 cps, with some divergence above 3 cps. A composite of these curves at 4.0 ma bias is shown in figure 1, curve A.

In the second test, bias current was held constant and sinusoidal current amplitude was varied. No appreciable change in phase was noted.

It was originally planned to test the calibrator under a static load equivalent to the weight of the strain member. However, previous tests of this nature did not indicate a change in phase response and this test was not attempted due to operational requirements.

2.2.2 Field Tests

Upon completion of the test series in Garland, the seismometer was assembled and transported to WMSO for operation in the plastic-cased borehole. It was found that the calibrator constant had changed from 4.5 mμ as measured in the lab to 9 mμ, measured under operational conditions. A phase response test of the vertical strain seismometer was run and the results are shown as curve B, figure 1.

2.2.3 Conclusions

All phase tests to date indicate that the phase lag noted in the output of the vertical strain seismometer during calibration is caused mainly by the MS calibrator. The phase correction curve used in the past has produced reasonably good results as evidenced by the similarity between data from the vertical strain and the sum of perpendicular horizontal strain seismometers. This curve (C) shown in figure 1, was obtained by mounting an MS calibrator on a horizontal strain seismometer.

It is interesting to note the similarity between correction curve (C) and that recently obtained under operational conditions. This similarity causes some doubt as to the validity of the phase tests performed in the laboratory. It is possible that the differences between the lab curve and the other curves were caused by differing environmental conditions; the calibrator was not loaded and was surrounded by a magnetic pole piece which may have changed the phase response.

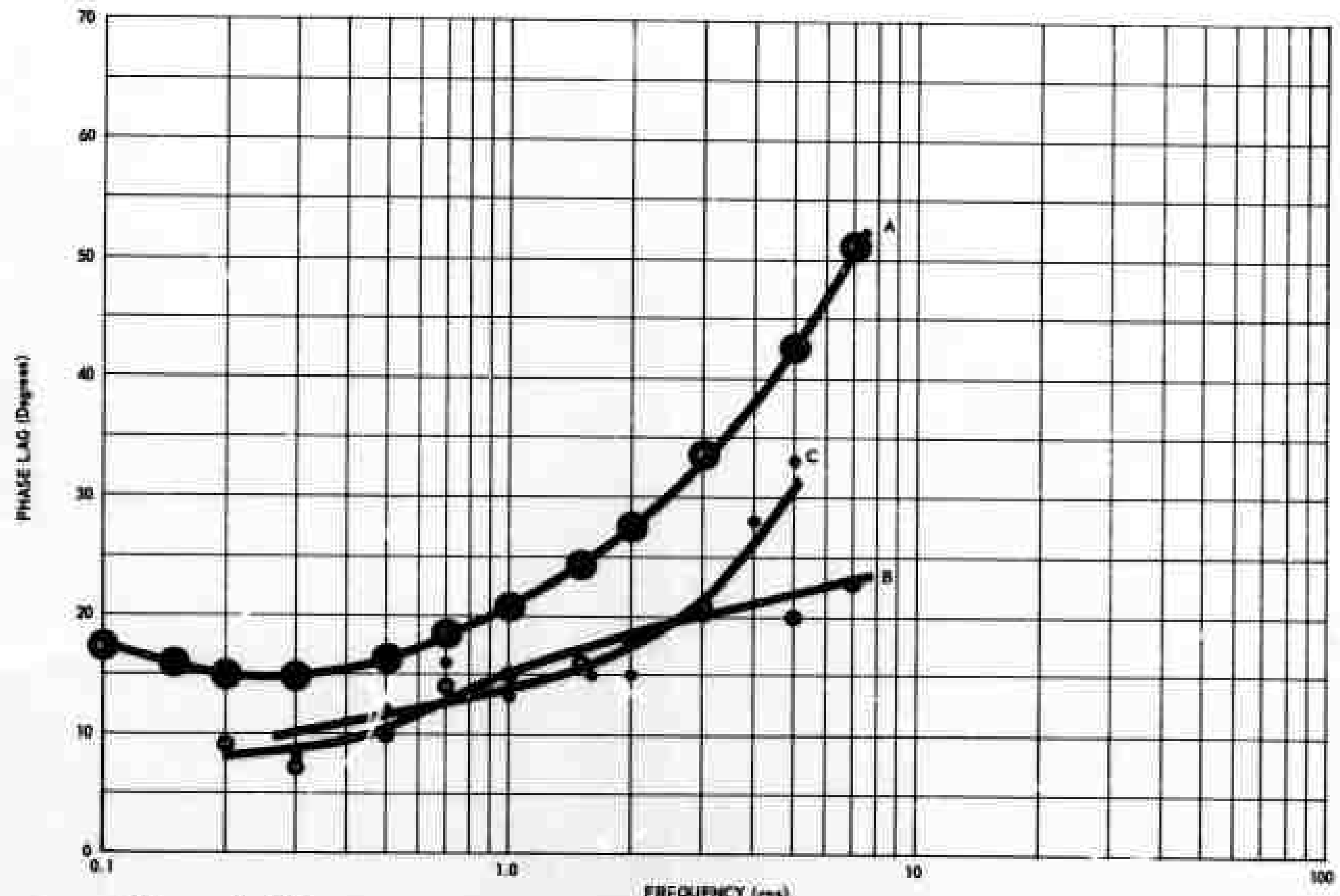

Figure 1. Phase response curves of the magnetostrictive calibrator under three test conditions: A - mounted in the vertical strain transducer package; B - mounted on the vertical strain seismometer; C - mounted on the horizontal strain seismometer

G 1675

Further testing of the phase response of the MS calibrator is necessary to resolve existing phase uncertainties , which are less than about 10 degrees below 3 cps, and larger than 10 degrees above 3 cps. It is considered necessary to mount a displacement transducer near the top of the strain tube to measure the phase and amplitude response of the MS calibrator under operating conditions.

2.3 SEISMOGRAPH PHASE STABILITY

Late during this reporting period, phase stability tests were begun on all systems. The purpose of these tests is to determine whether the instrumentation in each system has sufficient stability, both short term and long term, to insure a consistent phase relationship among strain and pendulum seismographs. Tests in progress include a daily three point phase response on the short-period vertical, strain east, and strain vertical. Also planned is a weekly five point response on all systems for at least two months.

Hourly phase measurements were made during an eight hour work shift on two consecutive days. Hourly readings on the short-period vertical, strain east, and strain vertical seismographs at 1.0 cps, show standard deviations of 1.2, 1.0, and 0.5 degrees, respectively. All deviations from the mean were within the rated accuracy of the phase measuring equipment used.

3. EVALUATION

3.1 VERTICAL STRAIN BOREHOLE WITH COMPLIANT CASING

Simultaneous operation of two identical vertical strain seismometers with VC transducers in the two boreholes at WMSO is necessary to evaluate the new plastic-cased borehole. The second seismometer was installed on 27 August 1966. Since then, friction in the transducer package has delayed data recording.

4. APPLICATIONS

4.1 RECORDING AND PROCESSING OF DATA

The following short-period seismograph outputs are being recorded on magnetic tape at WMSO:

2 vertical strain
4 horizontal strain
4 horizontal inertials
1 vertical inertial

These short-period seismographs occupy 11 tape channels. The recording of long-period data on magnetic tape will be delayed until channels are available. One channel will be available in a few weeks when the evaluation of the new borehole will probably be complete. It is estimated that four more channels will be available in about two months, if a sufficient number of earthquake signals have been recorded by that time to allow evaluation of the strain directional array.

Signals and noise samples are being dubbed on magnetic tape to retain signals for wave discrimination studies and to accumulate noise samples. Each noise sample is comprised of a 3-minute interval preceding each selected signal.

4.2 MEASUREMENT OF SPECTRA, PHASE, AND COHERENCY

4.2.1 Spectral Comparison of Vertical Strain and Summed Horizontal Strain

Romney (1964) showed that on the surface of the earth where the normal stress is zero for all wave types, the sum of any two orthogonal horizontal strains is proportional to the vertical strain. This relationship has been used to evaluate the operation of the vertical strain seismograph at WMSO. Spectra of the summed orthogonal horizontal strains, vertical strain, and summation of the vertical and horizontal strain seismograph outputs have been examined to evaluate the similarity of the vertical strain seismographs output to the output of the summed horizontal strain seismograph. Two 200-second microseismic noise samples were used for this study.

Prior to obtaining spectra, the magnification of the vertical strain seismograph was adjusted, for each noise sample, to provide a maximum reduction of signal in summation. Spectra of the summations compared to the spectra of the vertical and summed horizontal strain seismograph recordings of

microseismic noise have been used to provide a numerical measure of similarity by the equation below:

$$\text{SIMILARITY} = 1 - \frac{\text{spectrum magnitude of } \Sigma(SZ + SHS)}{\text{spectrum magnitude of SZ + spectrum magnitude of SHS}}$$

A similarity value of unity is attained when the outputs of the vertical and summed horizontal strain seismographs are equal in magnitude and opposite in phase. A value of zero is attained when the seismograph outputs are in phase, regardless of their magnitudes. At those frequencies where the vertical and horizontal strain seismographs satisfy the relationship shown by Romney, the values of similarity will be unity.

Spectra and similarity computed for one microseismic noise sample are illustrated in figures 2 and 3. Figure 2 is a plot of the spectral magnitudes of microseisms recorded by the vertical, summed horizontal strains, and their summation, and the phase difference between the spectra of the vertical and summed horizontal strains. From figure 2, the phase difference between frequencies 0.12 cps to 0.28 cps is observed to be nearly π. The high values of similarity shown in figure 3 indicate that the vertical and summed horizontal strain recordings are about equal throughout this band. From 0.3 cps to 1.0 cps, the magnitudes of the spectra drop rapidly; the phase differences range from about 0 to 2π; and the values of similarity drop from an average of 0.85, between 0.12 cps to 0.28 cps, to an average of 0.60. From 1.4 cps through 2.8 cps, the magnitudes of the spectra increase and the phase differences return to approximately π. The values of similarity also increase to an average of 0.78, excluding the low value at 2.4 cps. From 3.0 cps to 10.0 cps, the magnitudes of the spectra are low and the phase differences appear somewhat random. Similarly, the values of similarity range from 0 to 0.9 at random.

Figure 4 shows the combined values of similarity for the two microseismic noise samples processed. These values are the average of the similarity of both noise samples weighted by their individual spectral magnitudes. The values generally follow those illustrated in figure 3. The values are high where there are spectral peaks, but relatively low for most other frequencies.

To provide a guide to the interpretation of similarity, we computed the similarity between the spectrum of the vertical strain recording of one noise sample and the spectrum of the summed horizontal strain recording of the second noise sample. Since the samples were recorded at different times, the similarity should be low; figure 5, a plot of the similarity value computed, shows that it is.

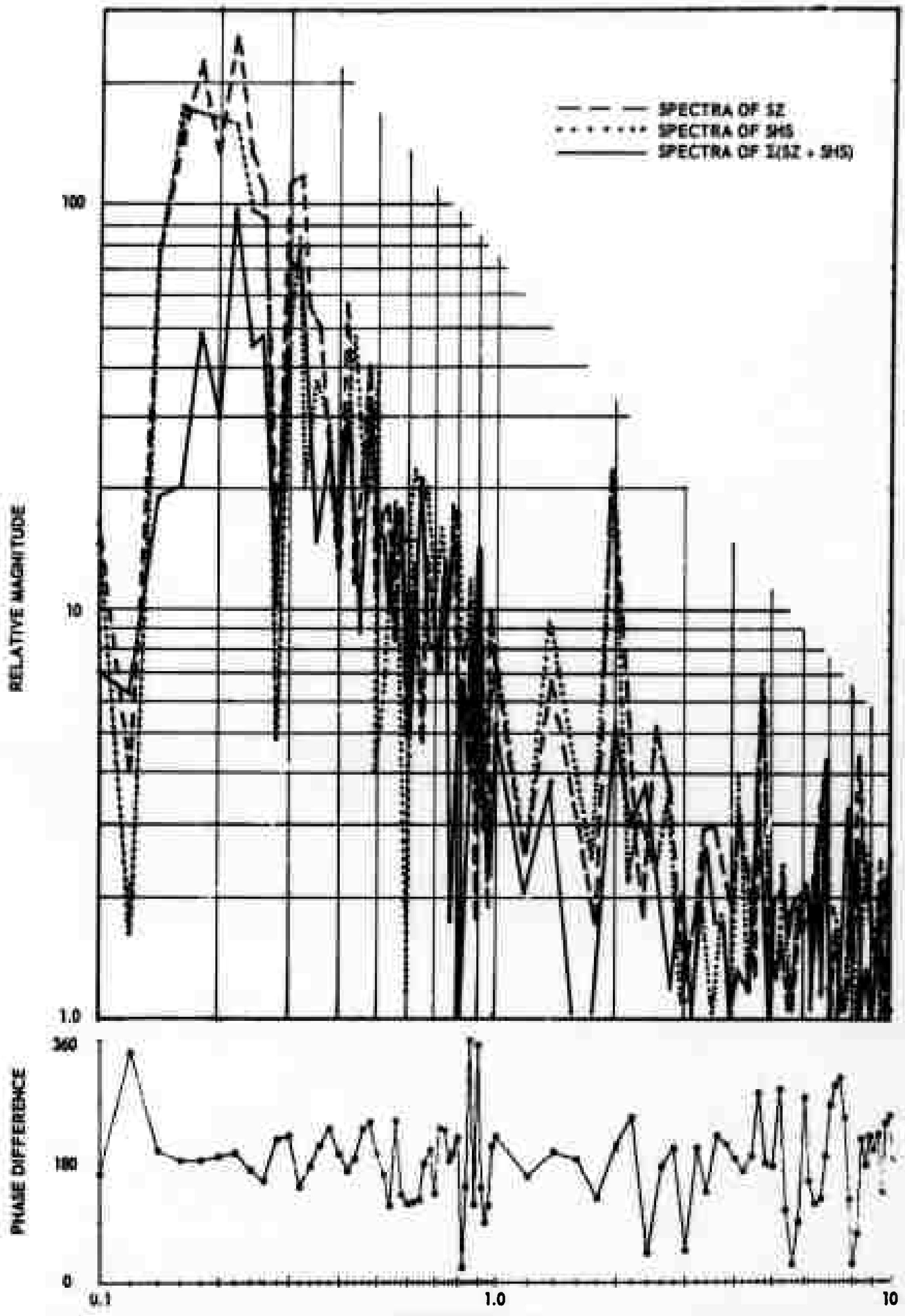

Figure 2. Spectra of microseisms for vertical strain [SZ], summed horizontal strains [SHS], summation of SZ and SHS, [Σ(SZ + SHS)], and the phase difference between the vertical and summed horizontal strain spectra

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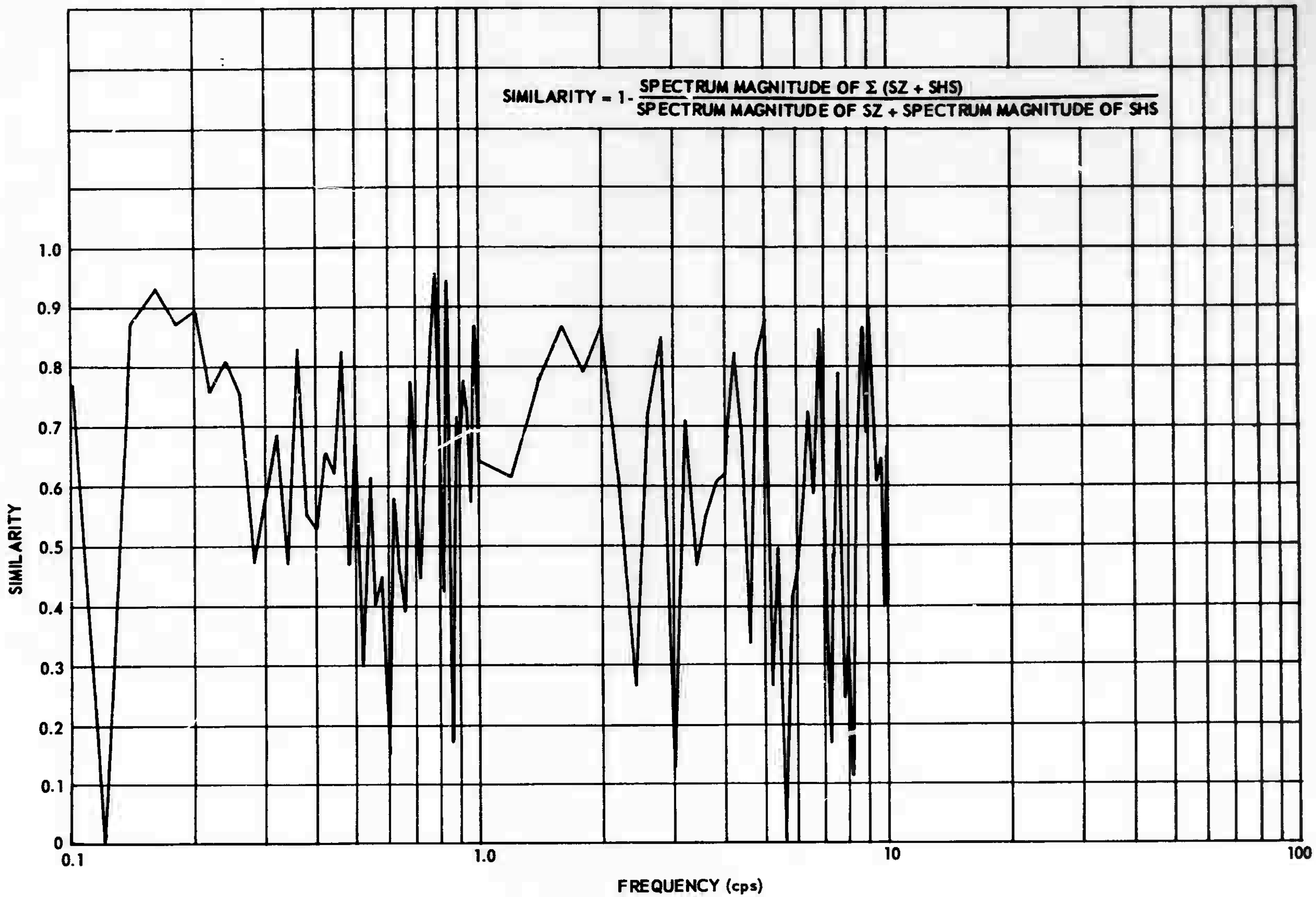

Figure 3. Similarity plot of the spectra of vertical strain (SZ) and summed horizontal strains (SHS)

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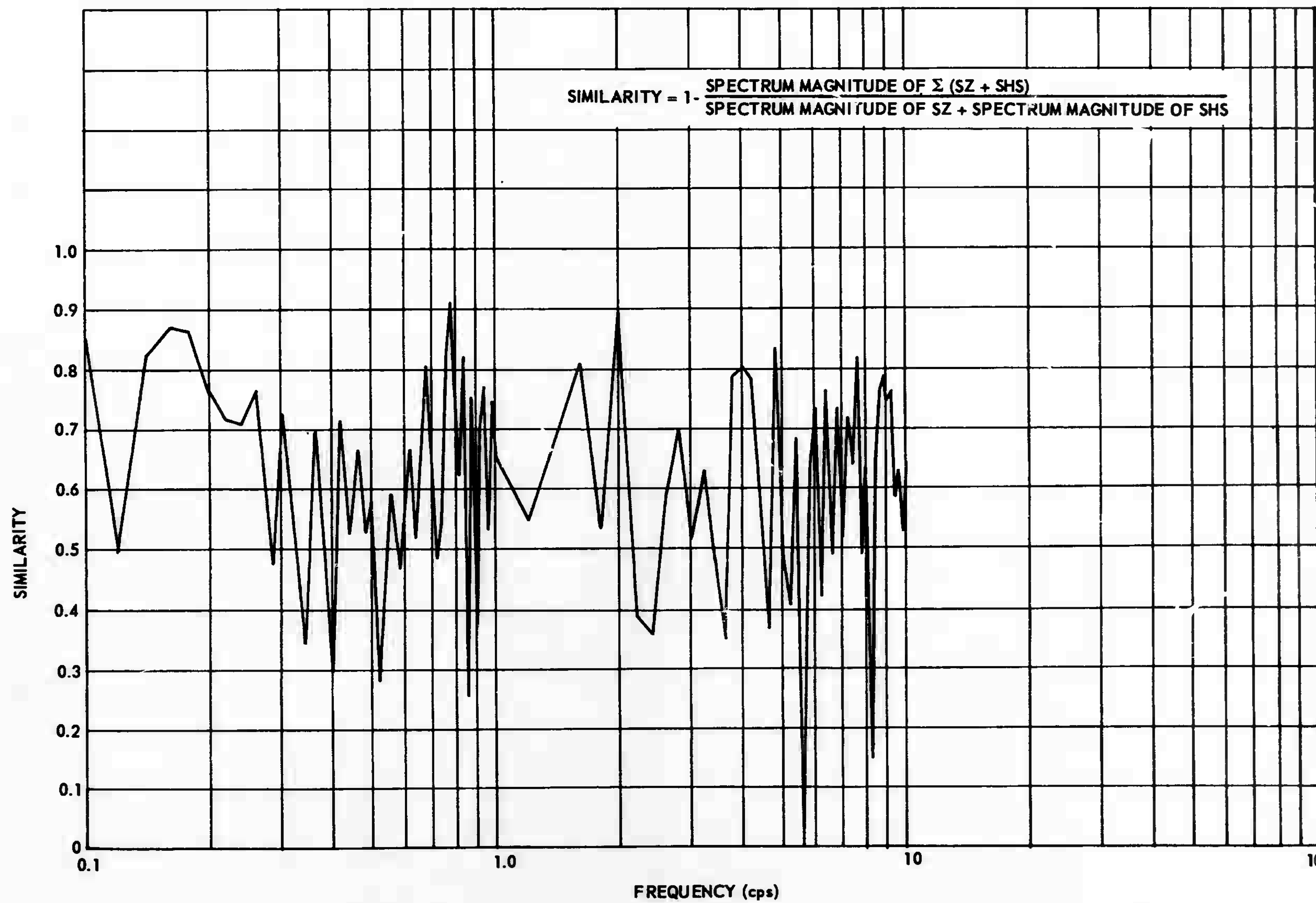

Figure 4. Plot of the combined values of similarity from the two microseismic samples processed

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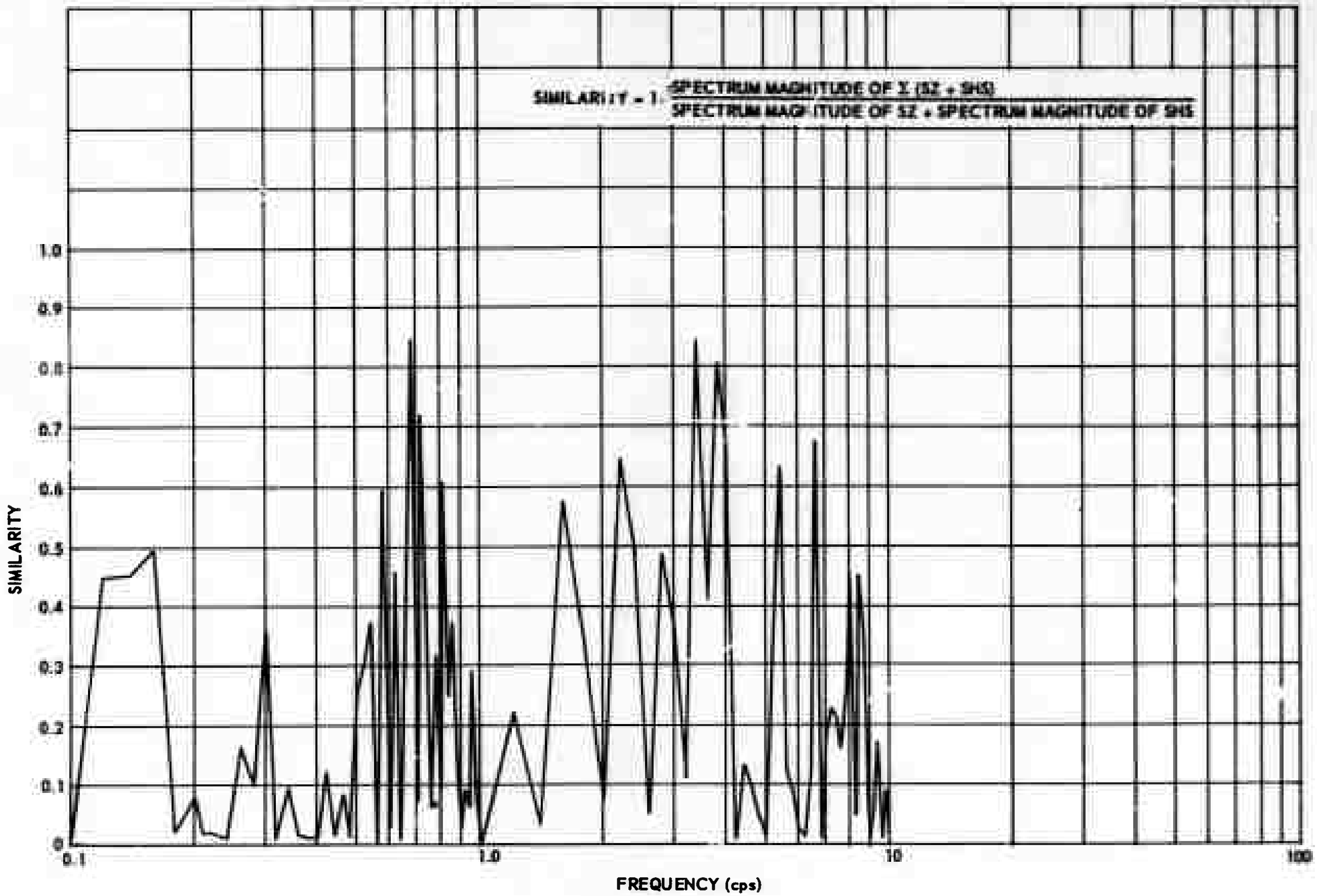

Figure 5. Similarity plot of the spectra of SZ and SHS where SHS was recorded at 1830Z on 27 January 1966, SZ was recorded at 0000 on 28 January 1966

G 1679

For purposes of simplification, the averages of the values of similarity over the bands 0.10 - 0.50 cps, 0.52 - 3.0 cps, and 3.2 - 10.0 cps for the data illustrated in figures 4 and 5 are tabulated below.

Band	Combined samp 1 & samp 2	ΣSZ of samp 1 + SHS of samp 2
0.10 - 0.50	0.65	0.13
0.52 - 3.0	0.61	0.28
3.2 - 10.0	0.60	0.21

Over the entire band, 0.10 - 10.0 cps, the similarity of the simultaneous recordings by the vertical and summed horizontal strains is about three times as great as that of the recordings made at different times.

Similarity computed for two microseismic noise samples indicate that the outputs of the vertical and summed horizontal strain seismographs are about equal when responding to high level microseisms only. Intermediate and low level microseisms yield lower values of similarity. These lower values do not imply a total lack of coherence, however. This becomes apparent when the similarity of either the single noise sample, figure 3, or the combined noise samples, figure 4, is compared to the similarity computed from two samples recorded at different times, figure 5.

4.2.2 Spectral Comparison of Horizontal Inertial and Horizontal Strain Seismograph Signals

The response of a horizontal strain seismometer to seismic waves was first discussed by Benioff (1935) and shown to differ from that of an inertial seismograph. In a paper published in 1962, Benioff suggested that the combined outputs of horizontal strain and inertial seismographs might be used to enhance the recording of earthquake signals by rejecting microseisms from selected azimuths. A study of the ability of the WMSO horizontal strain instrumentation to provide an improved signal-to-noise ratio over that of inertial seismographs has been undertaken. As part of the study, spectra of microseisms recorded by the horizontal inertial seismographs and by weighted summations of horizontal strain and inertial seismograph outputs have been examined. The summations will, henceforth, be referred to as strain-inertial seismograph combinations.

The usefulness of a horizontal strain-inertial seismograph combination is dependent upon the relative azimuths of a signal of interest and microseisms whose frequencies are near that of the signal. Since the azimuths of signal and noise may differ from event to event, the effectiveness of a specific horizontal strain-inertial seismograph combination is not static and a value

cannot easily be assigned as a measure of effectiveness. The following, therefore, is concerned with the reduction of noise as a function of frequency to determine if microseisms within given frequency ranges exhibit sufficient directional properties to be rejected by such a combination.

An attempt was made to reject only the largest-amplitude microseisms of each noise sample used in this study, with the exception of one particular sample containing known train noise generated at a railroad trestle 10 km south of WMSO, for which the strain-inertial seismograph combination was adjusted first to reject the largest-amplitude microseisms and then to reject the train noise. The latter case showed an average reduction of signal in the frequency range of train noise, 2.4 - 3.8 cps, of 9.7 dB relative to the inertial seismograph recording (figure 6). The appreciable reduction of signal demonstrates that a strain inertial combination could be adjusted to have a response that approaches zero for single-source apparent longitudinal waves, in accordance with theory. Some microseisms can be expected to occur in the frequency range of train noise that are of a different wave type and velocity or arrive from a different azimuth than the train noise thus accounting for the lack of total cancellation.

Figure 6 also illustrates that when the strain-inertial seismograph combination is adjusted to reject train noise, microseisms in the range 0.1 - 0.5 cps are added, showing about an average 1.6 dB increase over the microseisms of the same frequency recorded by the north inertial seismograph. The addition results because these microseisms arrive from an azimuth that is between 90° and 180° from the azimuth of the railroad trestle.

Table 1 contains values of average noise reduction of microseisms by the N and E oriented horizontal strain-inertial seismograph combinations for three noise samples. The values, expressed in decibels, were obtained by converting the ratios of the magnitudes of the inertial spectra to strain-inertial spectra into dB, then averaging for five different frequency ranges. Positive numbers show microseismic rejection, negative numbers indicate addition of microseisms.

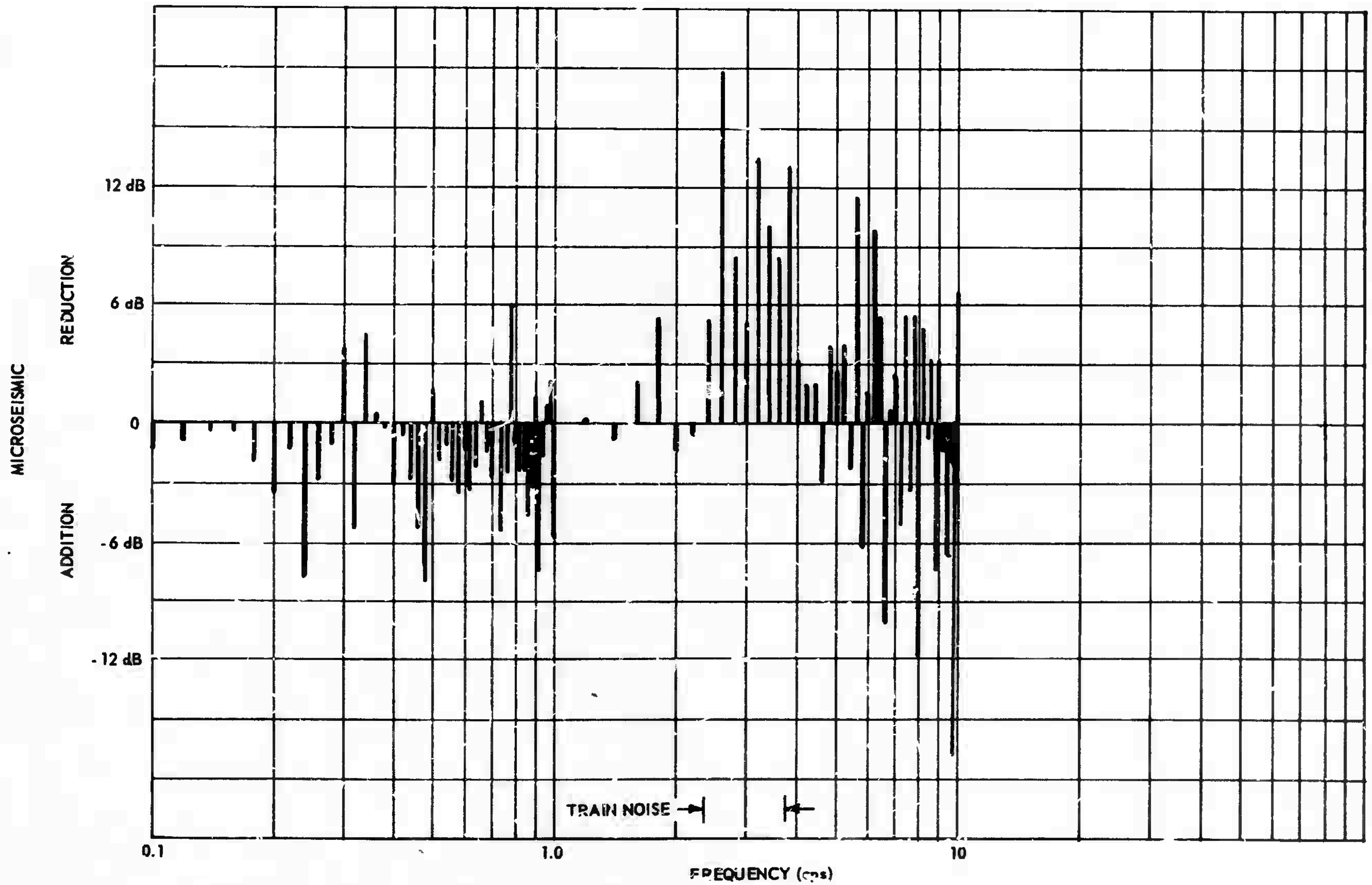

Figure 6. Ratios of the spectral magnitudes of the north oriented inertial to the strain-inertial combination expressed in decibels. Positive values indicate microseismic rejection by the strain-inertial combination; negative values indicate microseismic addition

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Table 1. Average noise reduction (in decibels) of microseisms from three noise samples processed from the north and east horizontal strain-inertial combination

		Reduction in decibels				
		Frequency range (cps)				
Date & time sample taken	Instrument combination (N - North, E - East)	0.10-0.30	0.32-0.50	0.52-1.4	1.6-4.0	4.2-10.0
27 Jan. 66 1830Z	N	2.3	2.9	2.1	-2.9	-0.6
	E	4.4	2.0	3.0	-0.6	2.1
28 Jan. 66 0000Z	N	2.2	4.6	2.3	0.9	-0.7
	E	4.2	3.3	2.5	0.0	2.7
28 Jan. 66 0030Z	N	2.6	3.0	3.1	-6.2	-2.2
	E	7.4	7.0	0.7	-1.2	-0.1

The third sample shows a reduction of 2.6 dB, 3.0 dB, and 3.1 dB by the north oriented combination in the ranges 0.1-0.3 cps, 0.32-0.5 cps and 0.52-1.4 cps, respectively. However, microseismic addition of 6.2 dB was attained in the range of 1.6-4.0 cps. This particular sample is the same sample illustrated in figure 6. However, reduction of microseisms from the north between 0.1 cps and 1.4 cps, was sought in this case rather than a reduction of train noise from the south. By reducing northerly microseisms in the range 0.1-1.4 cps, the 2.4-3.8 cps train noise was added.

The sample recorded by the east oriented-combination for the same time interval shows a large reduction (7.0-7.4 dB) of microseismic noise in the range 0.1-0.5 cps. The reduction of noise in this range indicates that a significant portion of the microseisms in that frequency band were arriving from an easterly direction. The other samples recorded by both the north and east oriented combinations show less microseismic rejection (2.0-4.0 dB); however, that all samples show rejection rather than addition over 0.1-1.4 cps indicates the capability to improve signal-to-noise ratio over both N and E inertial seismographs.

The samples examined in this study show the strain-inertial seismograph combinations to have azimuthally dependent responses to microseisms as expected from theory. The microseisms that occurred during the three periods of time examined also showed sufficient directionality over a wide range of frequencies to be partially rejected by the strain-inertial seismograph combinations. The horizontal strain-inertial seismograph combinations can, therefore, be expected to provide improved S/N ratios over inertial seismograph recordings of earthquakes that arrive from azimuths greater than 90° from the azimuths of the predominant microseisms.

4.3 VERIFICATION THAT TRUE EARTH STRAINS ARE FAITHFULLY RECORDED BY THE VERTICAL STRAIN SEISMOMETER

4.3.1 Criteria

Sufficient data have been analyzed to conclude with reasonable certainty that true earth strain is being faithfully recorded by the vertical strain seismometer. Discussed below are three criteria used in reaching that conclusion.

4.3.2 Criterion No. 1 - Ratio of Vertical Strain to Vertical Displacement

A theoretical value of 0.007 has been computed for the ratio of vertical differential particle displacement to particle displacement at 1 cps based on Rayleigh's equations for the vertical component of particle displacement as a function of depth for Rayleigh waves in a uniform half-space. Measurements from strain and inertial data at WMSO give a value of 0.011 at 1 cps. These values are reasonably close, considering that they are based on the assumption of a uniform half-space.

4.3.3 Criterion No. 2 - Vertical Strain is Proportional to Summed Orthogonal (Crossed) Horizontal Strain

The theoretical relationship between vertical strain (SZ) and summed crossed horizontal strain (SHS) at the surface is given by the equation

$$SHS = -3SZ \tag{1}$$

The value of the multiplier constant for 1 cps Rayleigh waves in the surface phase of the local event of figure 10 is 2.7. The factor of depth of operation of the vertical strain seismometer may have some bearing on the magnitude of the multiplier constant, since the value of 3 holds only at the surface of the earth.

Equation (1) also implies that the vertical and crossed horizontal strain outputs are identical in character. The degree of similarity of signals is indicated in figures 7 and 8 where cancellation values of about 12 dB prevail. Improvement in similarity will be sought by operating the vertical strain seismometer closer to the surface.

4.3.4 Criterion No. 3 - Matching of Vertical Strain and Vertical Inertial Seismograph Outputs

Theory indicates that vertical strain due to the occurrence of the fundamental mode Rayleigh wave will be in phase with earth displacement but will have an amplitude-frequency response curve whose slope will be 6 dB per octave steeper than the curve of earth displacement as a function of frequency. By appropriate selection of strain and inertial transducers, galvanometers, and filters, strain and inertial responses can be equalized. The degree to which empirical and theoretical data agree are indicated by the excellent (15 dB) cancellation of Rayleigh waves in the surface phase of two local quarry blasts from the same epicenter (figures 9 and 10). The body waves, as expected, are not cancelled. The first event occurred on 4 February 1966 during which time the vertical strain seismometer was operating in the steel-cased borehole at WMSO. The second event occurred on 1 July 1966 when the instrument was in the plastic-cased borehole.

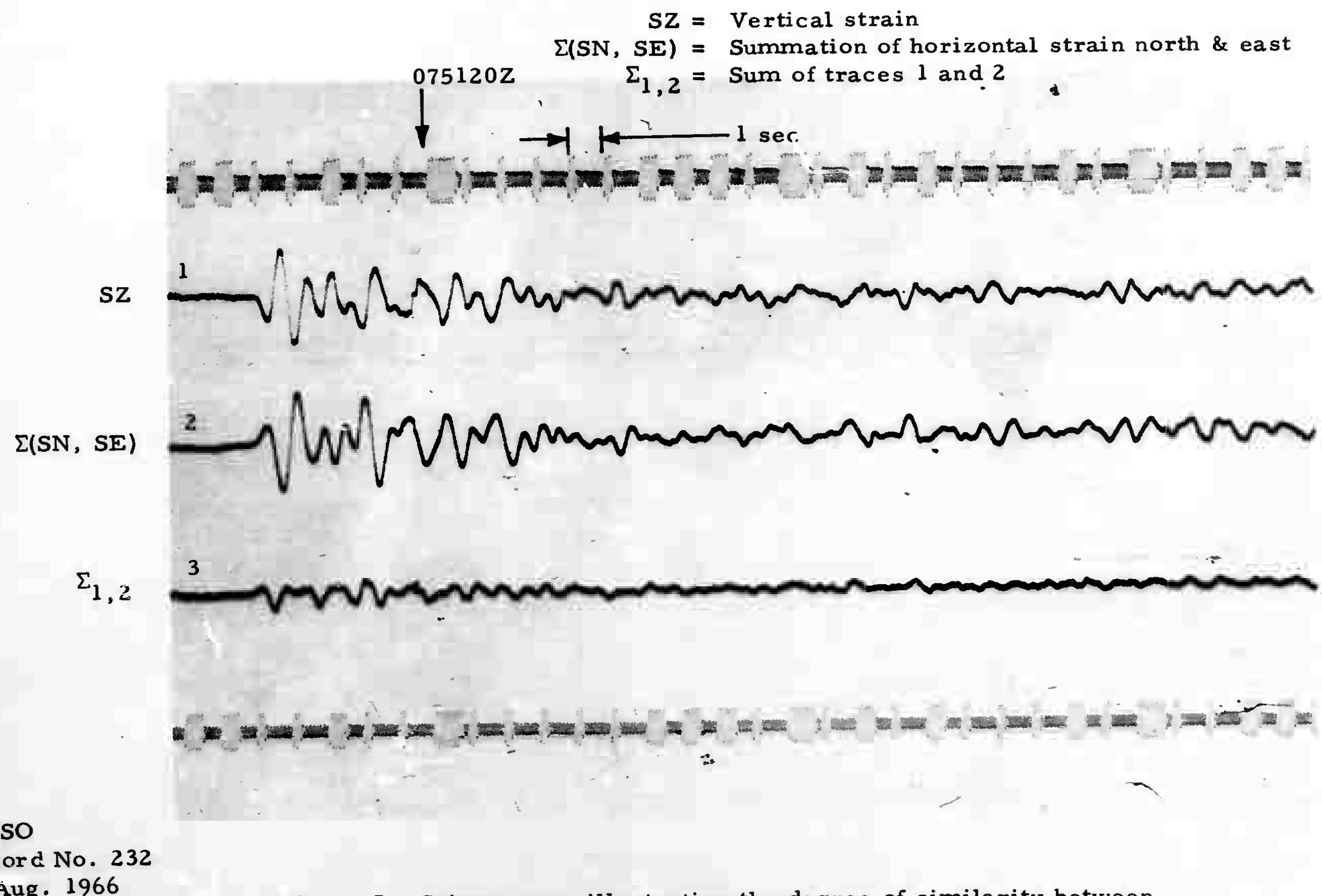
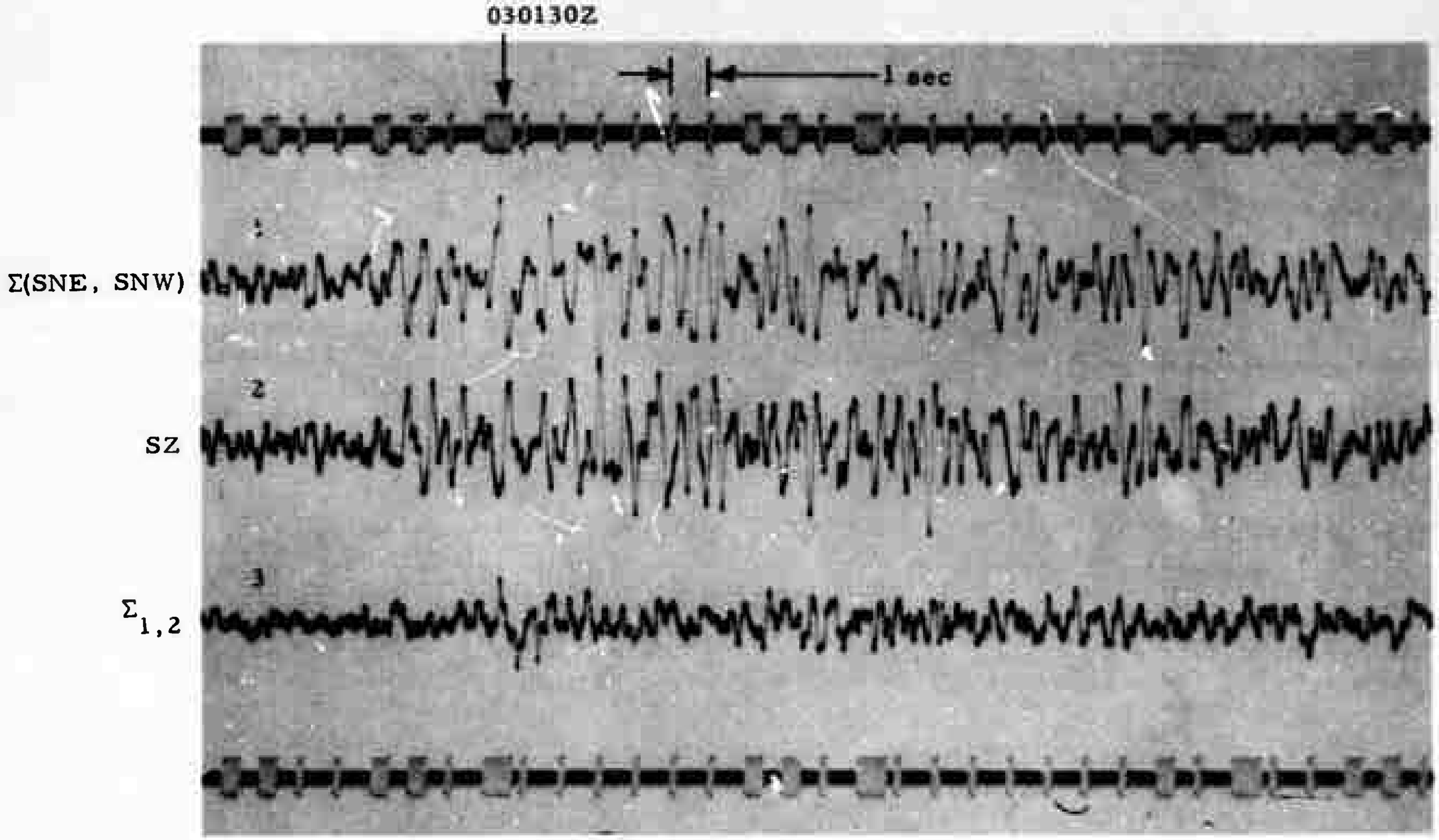


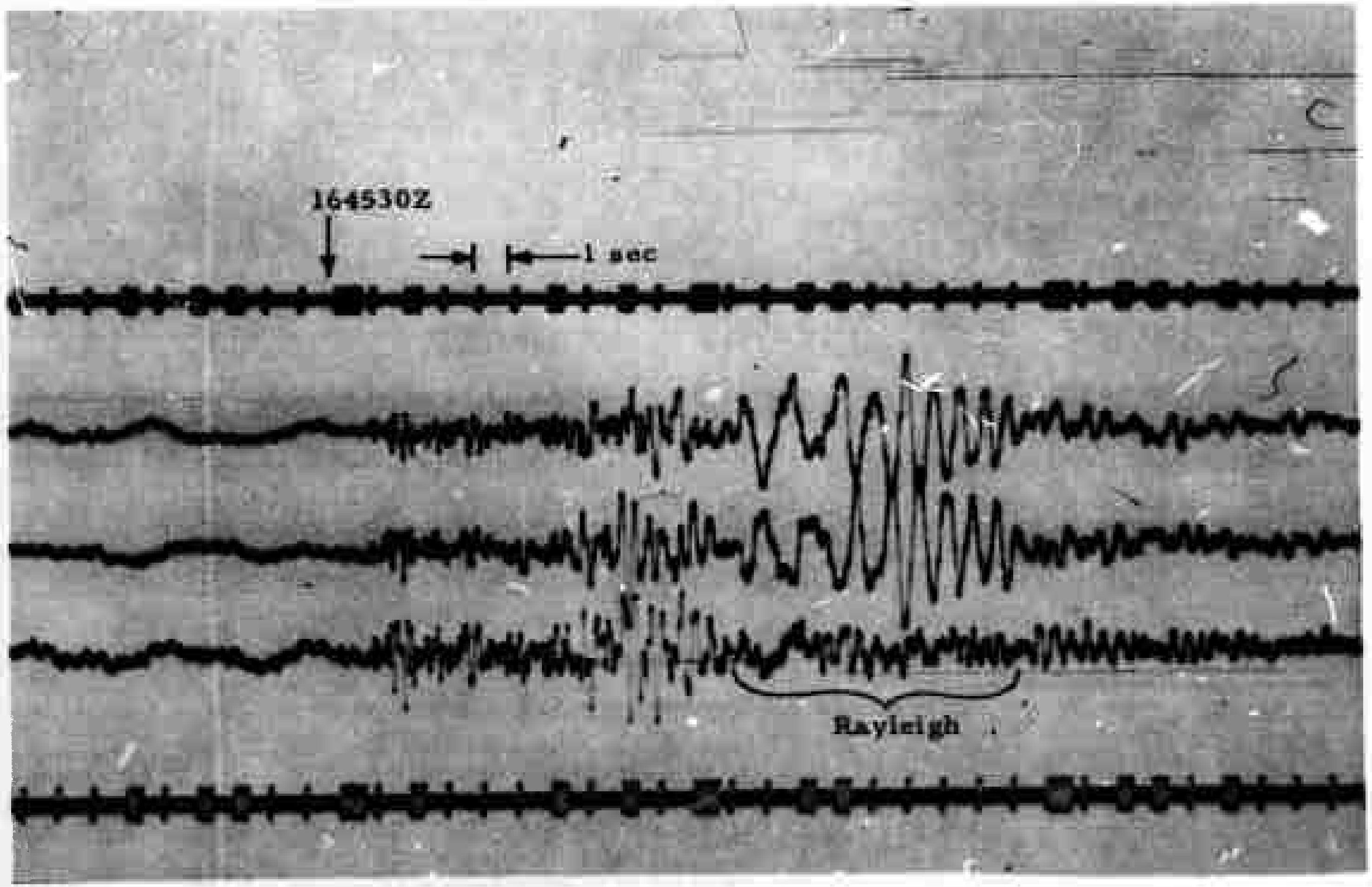
Figure 7. Seismogram illustrating the degree of similarity between vertical strain and crossed-horizontal strain outputs for the P phase of a teleseism ($\Delta = 43^{\circ}$, $h = 116$ km)



WMSO
Record No. 233
21 Aug. 1966

Figure 8. Seismogram illustrating the degree of similarity between vertical strain and crossed-horizontal strain outputs for the surface phase of a regional event ($\Delta = 7.5^{\circ}$, AZ = WSW)

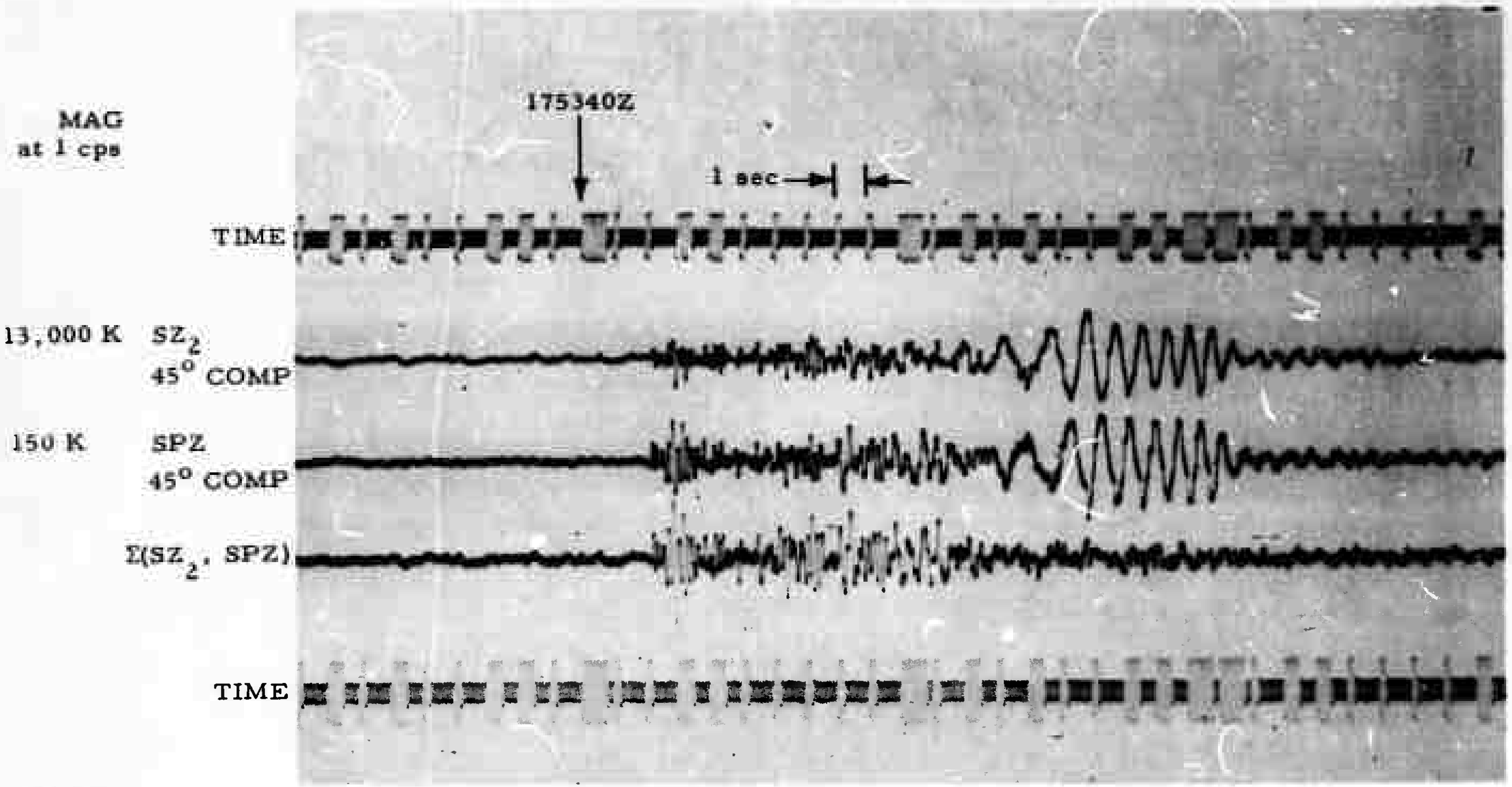
SZ_1 Refers to vertical strain seismometer in steel-cased borehole



WMSO
Record No. 035
04 Feb. 1966

Figure 9. Seismogram illustrating degree of similarity between vertical strain (SZ_1) and vertical inertial seismograph output (SPZ) for Rayleigh waves near 1 cps from a local quarry blast

SZ_2 Refers to vertical strain seismometer in plastic-cased borehole



WMSO
Record No. 182
01 July 1966

Figure 10. Seismogram illustrating degree of similarity between vertical strain (SZ_2) and vertical inertial seismograph output (SPZ) for Rayleigh waves near 1 cps from a local quarry blast

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APPENDIX TO TECHNICAL REPORT NO. 66-93

STATEMENT OF WORK TO BE DONE

AFTAC PROJECT AUTHORIZATION NO. VELA T/5081

EXHIBIT "A"

STATEMENT OF WORK TO BE DONE

AFTAC Project Authorization No. VELA T/5081

1. Instrumentation Development

a. Complete the development of the variable-capacitance transducer to extend the strain seismograph response to longer periods.

b. Complete the modification and testing of the seismometer transducers, amplifiers, filters, and associated circuitry to insure a consistent phase relationship between pendulum and strain seismographs.

c. Design and install secular strain monitors to improve the horizontal strain seismograph operation.

d. Improve the stability of the seismograph circuitry by installing a separate phototube amplifier shelter.

2. Seismograph Development

a. Vertical Strain Seismograph

(1) Complete this design of the vertical strain seismograph by improving the anchor design, reshaping the instrument sections, and improving the mechanical reliability relative to installation, position locking, and removal.

(2) Improve the operation of the vertical strain seismograph by incorporating the developments listed in paragraphs 1a, 1b, and 2a(1).

b. Horizontal Strain Seismographs

(1) Improve the design of the horizontal strain seismographs by the addition of secular strain controls and seismograph housing modifications.

(2) Improve the operation of the horizontal strain seismographs by incorporating the developments listed in paragraphs 1a, 1b, 1c, 1d, and 2b(1).

3. Evaluation

a. Vertical Strain Seismograph. Test and evaluate the operation of the improved vertical strain seismograph in a new uncased borehole to be located adjacent to the present cased borehole. The uncased borehole is to be oil-filled and may contain the following features:

(1) Steel casing sections may be used for instrument anchor locations if the sections are decoupled from each other so that longitudinal casing rigidity is less than that of the surrounding rock formation.

(2) A continuous plastic casing may be used to maintain wall smoothness and hole integrity provided that the plastic is more compliant than the surrounding rock formation.

(3) Combinations of (1) and (2) may be used. In all instances where instrument achors must lock against a borehole liner, the liner must be rigidly bonded to the borehole wall.

To facilitate the positioning of the instrument in the borehole, a permanent anchor may be used in the cased and uncased holes. This fixed depth operation might help to avoid the anchor malfunctioning which has been experienced.

b. Horizontal Strain Seismographs. Test and evaluate the operation of the improved horizontal strain seismographs in their improved housing.

4. Applications

a. Record seismic data at Wichita Mountains Seismological Observatory on magnetic tape and 16 mm film; process magnetic tape data at the Geotechnical Corporation's central data processing facility and elsewhere as required; and determine spectra, phase, and coherency among the vertical strain, horizontal strain, and several pendulum seismometer control signals.

b. Experimentally corroborate the vertical strain seismograph performance relative to the 2 crossed-horizontal strain seismographs to verify that true earth strains are faithfully recorded by the vertical strain instrument.

c. Develop a thorough understanding and evaluation of the phase and amplitude performance of the strain seismographs and related pendulum systems.

d. Determine the usefulness of strain seismographs when used singularly and in combination with inertial instruments for wave identification, signal enhancement, detection of long-period signals, and rejection of noise arriving from selected azimuths. Determine the usefulness of strain seismographs in distinguishing between earthquakes and explosions. Schedule the program so as to provide preliminary results on the P-wave enhancement portion of the program not later than 30 Sept 65.

*5. Drawings. Provide drawings and specifications on items specified in paragraphs 2a(1), 2a(2), 2b(1), 2b(2), and the uncased borehole as outlined in paragraph 3 according to Data Items E-23-11.0, E-2-11.0, E-4-11.0, E-5-11.0, E-7-11.0, and T-13-28.0 contained in AFSCM 310-1. These drawings shall conform to the instructions contained in Attachment 2. Wherever Data Items conflict with Attachment 2, the latter will take precedence. Reproduction shall be accomplished in accordance with Data Item E-4-11.0, paragraphs 1b, 1f, 7, 9, 10, 11, and 12c(3), microfilm on aperture cards and nonreproducible paper copies. Index card keypunch format may vary from specifications as approved by AFTAC through the project officer. Aperture cards should be furnished in 2 copies, 1 positive and 1 negative.

6. Reports. Provide monthly, quarterly, final, milestone, and special progress reports in accordance with Data Item S-17-12.0, first sentence of paragraph 1. Wherever the Data Item conflicts with Attachment 1, the latter will take precedence. All reports under this project will be forwarded to HQ USAF (AFTAC/VELA Seismological Center), Wash., D. C. 20333.

*For the purposes of this contract, the provisions of paragraph 5 of this Exhibit "A" are hereby waived. In lieu thereof, the following provisions shall apply:

"5. Drawings. Drawings shall be furnished in accordance with the provisions of line item 7 of the DD Form 1423 and attachments thereto."

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

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Qualified requestors may obtain copies of this report from DDC

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

Phase response tests of the magnetostrictive calibrator on the vertical strain seismometer indicate that the calibrator is the chief cause of phase lag measured at the output of the seismometer during calibration. Further tests are necessary to resolve existing phase uncertainties, which are less than about 10 degrees at frequencies below 3 cps, and larger than 10 degrees above 3 cps.

Spectra of microseisms recorded by the vertical strain, crossed horizontal strains, and their summation were examined to determine the similarity of the outputs of the strain seismographs. Only at spectral peaks were the vertical and crossed horizontal strains found to have about equal response.

A preliminary examination of the ability of the north and east summed horizontal strain and inertial seismographs to reject microseisms was undertaken employing spectra. Reduction of about 10 dB was attained for single source microseisms.

The conclusion that true earth strain is being recorded by the vertical strain seismometer is supported by two results: (1) Rayleigh waves at 1 cps are cancelled by at least 15 dB by summing vertical strain and vertical inertial seismograph outputs; (2) The empirical value of the ratio of vertical strain to summed orthogonal horizontal strain is within 12 percent of the theoretical value for Rayleigh waves at 1 cps.

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